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DEVICE FOR CENTERING AND SUSPENSION BY MAGNETIC BEARINGS, OF  
TURNING BODIES, IN PARTICULAR IN A SEALED ENCLOSURE

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DEVICE FOR CENTERING AND SUSPENSION BY MAGNETIC BEARINGS, OF  
TURNING BODIES, IN PARTICULAR IN A SEALED ENCLOSURE

[Dispositif de centrage et de suspension par paliers magnetiques, de corps tournants, notamment  
dans une enceinte étanche]

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The centering and suspension of turning bodies, in particular the motor-compressor sets situated in dangerous environments, which risk deteriorating them or being contaminated by them, has led, on one hand, to pushing the conventional sealing and swiveling devices to a high degree of perfection, and on the other hand, to looking for new solutions of general scope. Among them, the stress has more particularly been put on magnetic or electromagnetic devices which act in a radial or axial direction, and which we will designate under the general term magnetic bearings.

It is this type of component and the bodies which it supports to which the invention relates, and the invention relates more particularly but not exclusively to magnetic bearings which support, in a sealed enclosure, moving bodies given a high speed of rotation, for example, motor-compressor sets.

The invention aims to provide them with improvements in their constitution and functioning.

Different devices have been proposed in the past, in which rotary machines moved by ordinary electric motors are mounted on a shared shaft borne by electromagnetic bearings provided with a servo control device making them stable, that is to say that they tend to return to their initial position when some force takes them away from it. The choice of a solution of such type involves large dimensions for the electromagnets which are used; their long response times are detrimental and incompatible with the correction of small disturbances in the required time periods.

Earnshaw demonstrated more particularly (theory of magnetism) that in a magnetic field of constant intensity, a body sensitive to this field and floating freely in it is at unstable equilibrium, which under these conditions more precisely means that this body cannot be stable according to the three directions of space, but at most according to two of them.

The invention, which takes into account these very general properties of magnetic and mechanical phenomena, differs considerably from the earlier executions. In the case of guiding and of magnetic support of the components of a rotary machine, it consists of using magnetic bearings which are naturally stable, that is to say without servo control, in two directions of space in general, of combining them with driving and driven components which are as much as possible indifferent to displacement in said directions, and finally of entrusting the guiding in the additional direction(s) (necessary to complete their total number to three) to one (or more) bearings necessarily of a different nature, if necessary stabilized by a servo control. This (or these) bearing(s) can more particularly be mechanical, aerodynamic or hydrodynamic, and finally electromagnetic but with servo control, and they will themselves act in a direction of space according to which at least certain of the driven and driving components, but in any case the smallest possible number of them, have an instability, or even variable characteristics pulling the instability of the magnetic system in said direction, and by this very fact, the corresponding bearing which cannot be magnetic and stable at the same time.

It moreover consists of certain arrangements which are used preferably at the same time and will be disclosed further on.

It relates more particularly to a certain mode of application to the magnetic bearing which support, in a sealed enclosure, moving bodies given a high speed of rotation, and to certain embodiments of these arrangements.

The description which follows with regard to the appended drawing given as a non-limiting example will enable one to fully understand how the invention can be executed; the particularities which emerge from the drawing as well as from the text of course are part of said invention.

Figure 1, a skeleton diagram, represents a moving body with horizontal axis turning on magnetic bearings and provided with mechanical stops.

Figure 2 is a diagram of application to a centrifugal motor-compressor set with horizontal axis provided with a servo controlled electromagnetic stop.

Figure 3 gives, in section, the constitution of said stop.

Figure 4 is a diagrammatic view in section of a mechanical safety stop.

Figure 5 shows an aerodynamic balancing device.

Figure 6 is a diagram of application to a moving body with a vertical axis turning on magnetic stops and provided with mechanical bearings.

Figure 7 is the diagram of a stable magnetic stop.

In order to disclose the invention simply, two examples are described of rotary moving bodies of which the weight is supported by a stable magnetic component, but the axis of one is horizontal whereas it is vertical in the other case. Even if this way of doing it seems preferable, it cannot however be considered to be exclusive.

Figure 1 represents a mode of suspension which Figures 2 to 5 illustrate more precisely as well as its variants. Axis 1 is supported at both of its ends 1a and 1b by radially stable magnetic bearings 2a and 2b. Two mechanical stops 3a and 3b palliate the axial instability. An electric motor with rotor 4 drives the assembly and provides energy to receiver 5 not represented in Figure 1. Finally, two radial deadening devices 6a and 6b, which will be described in detail further on, go into action when shaft 1 is taken away from its average position.

The magnetic bearings can be formed using electromagnets, magnets, and more particularly toric-shaped ferrite cores with magnetically oriented grains. A preferred mode of assembly providing particularly stable guiding consists of arranging such cores with rectangular section 11 and 12 side by side, alternately turning and stationary, with the same axis as the moving body, and of which the flat pole sides opposite one another have opposite signs. The stationary part has reinforcement armature 13 made of permeable material which reduces the magnetic losses. Such ferrite cores have the property, due to their high ohmic resistance, of causing low losses through eddy currents. Since bearings 2 have a symmetrical construction, one sees that they do not introduce axial magnetic force in the position of symmetry which is a position of equilibrium. In contrast, any displacement from said position creates a force directed in the same direction as it, making said equilibrium unstable. It is therefore necessary to use different axial guiding means, which can advantageously be mechanical means with low friction.

Thus, stops 3 can be simply made up of ball bearings having a minimum of longitudinal play. Even though two such stops 3a, 3b are diagrammatically represented in Figure 1, making it possible, by the bilateral connection (in the mechanical sense) which they create, to maintain the moving body in a small interval surrounding the unstable position of equilibrium without having to resist an appreciable force (this force even being zero in this position), it is possible however to deliberately go to one given side of this position and to use only a single stop, with the very unbalanced force used to lay ball 14 of this stop against stationary surface 15, thus making the second stop unnecessary.

This force is due to bearings 2a and 2b, but rotor 4 of the electric motor can also contribute towards creating it. The invention then consists at the same time of using motors with the particular properties of which a non-exclusive execution is known as flat engine. Such a motor has a roughly flat rotor, and the active conductors which it bears, which are often produced by the printed circuit technique, are roughly radial and the flux which they contain varies only very little in a radial displacement of said rotor and furthermore in an axial displacement. The corresponding magnetic forces are minimal, which causes these motors to be called "pure torque motors". In contrast to the usual motors, they act little upon their bearings in case of misalignment, which incites one to combine them with the magnetic bearings described above. Any other type of motor free of radial reaction could be used in the combination to which the invention relates.

The stability of the magnetic bearings furthermore does not exclude oscillation around their position of balance during the return towards it, if some impulse took it away from there, hence the usefulness of deadeners.

Figure 1 shows mechanical deadeners at 6a and 6b made up of simple contacts with low tangential friction and radial elastic return by spring. Any other radial force could be substituted for them if its tangential component remains low, and equivalent executions can be imagined, which would create said force, making use of electricity or fluid mechanics.

Using this diagram, it is possible to describe certain variants. Figure 2 is applied to a sealed motor-compressor set with horizontal axis provided with a servo controlled electromagnetic stop. The moving body has centrifugal wheel 5 mounted projecting at end 1a of shaft 1, which in its rotation compresses a fluid arriving at 16 and leaving at 17. The device for centering, support and movement of shaft 1 is entirely contained in sealed casing 18, which is connected however by pipe 19 to space 16 at lower pressure. This makes it possible to adopt a lighter construction by preventing the pressure in enclosure 18 from rejoining, because of lateral leaks of wheel 5, that of delivery, which has another consequence, that of making possible an aerodynamic balance of said wheel represented in Figure 5. Enclosure 18 contains two stable magnetic bearings 2a and 2b, the electric motor with flat rotor 4, radial stabilizer or deadener 6

and servo controlled electromagnetic stop 7 whose use involves, in case of electrical breakdown, the existence of mechanical safety stops 8 (Figure 4).

The servo-controlled electromagnetic stop represented in Figure 3 is composed essentially of a magnetic system which has magnetized core 20 concentric to shaft 1, in the air gap of which coil 21 is placed, whose field can be adjusted under the effect of a position detector made up, for example, of differential transformer 22 situated in the axis and whose impedance varies with any displacement of soft steel sight borne by end 1b of shaft 1. An amplifier, driven by transformer 22 and used for supplying coil 21, forms, with these components and the shaft, a looped servo mechanism for which the stability can be calculated by the usual electrical theories and details of which will not be given. It moreover has mechanical accessories; in case of failure, mechanical stops ensure the guiding for which the magnetic execution then is lacking.

Stop 8b can be produced by a surface erected perpendicular to the axis of the moving body, cooperating with another erect surface connected with the stationary support structure and produced out of a material with a low friction coefficient such as graphite-teflon. Said stop 8b can at the same time have mechanical radial safety guide 24, preventing damage to coil 21 in case of possible misalignment. But since it acts axially only in one direction, it must be associated with a second mechanical safety stop 8a which acts in the opposite direction. Stop 8a diagrammed in Figure 2 and represented in detail in Figure 4 has a flat erect surface of shoulder 25 borne by shaft 1 near its end 1a. This surface is opposite (and a short distance away when the servo controlled electromagnetic stop is functioning) erect surface 26 of plate 27 with low friction, borne by the stationary support structure to which it is connected by spring 28, on one hand, with it possible for bellows device 29 to play the part of dash-pot, on the other hand. If the wheel is well balanced axially by aerodynamic means, this stop only opposes the forces developed by the rotor of the motor and the bearings, it therefore can be of light construction.

An embodiment of this axial balancing of wheel 5 is represented in Figure 5. The aerodynamic axial force, due to the fact that the difference in the pressures between the downstream and upstream of the wheel is exerted on the surface of it opposite intake pipe 16, is balanced by the pressures exerted on both sides of plate 30 which is attached on shaft 1 near its end 1a and which turns with it. Taking into account the load losses in the various leak spaces 31, 32, 33, 34, the diameter of this plate can be chosen in such a way that the result of the pressures which it supports, oriented toward the right of the drawing, exactly opposes the result, oriented toward the left, of the pressures on the surface of the wheel. In effect, if said plate 30 is subjected on one of its surfaces to the pressure in enclosure 18, which is close to that predominating at 16, its other surface is subjected to a pressure closer to that predominating in outlet 17, which is established by leaks at 32 and 33. The small radial play 33 creating the load loss can furthermore be arranged between shaft 1 and a safety sleeve 35 with a low friction coefficient, making it

air gaps of at least one of the stops can be unequal, for the purpose of equalizing the magnetic return forces towards the balance on both sides of it.

Finally, the radial stabilizing torque introduced by the weight and upper mechanical bearing 2b made up, for example, of a graphite-teflon ring cooperating with a journal of the shaft, can be sufficient to exceed in value the radial instability of the magnetic stops and to allow the replacement of the bearing represented in Figure 1 by a safety component with wide play. A stabilizer can possibly be arranged at end 1a, which can be used for axial deadening as well as for radial deadening, and of which a mechanical diagram can be given by a spring contact borne by the stationary support structure and situated in an axial recess, with oblique walls, of the shaft.

It goes without saying that other embodiments using equivalent components can be substituted for this one.

The observation relating to the size of the various gaps disclosed above is also valid.

In all the cases, if the air gaps used are wide enough, it is possible to do away with sealed casing 18.

Neither the mode of application nor the embodiment indicated can be considered to limit the invention, and other motors, receivers and even their combinations, if they have similar mechanical properties, can be included, more particularly when they are used to treat toxic or corrosive products, as the chemical industry often uses, and even if they must simply function without maintenance in a sealed enclosure.

#### Summary [Claims]

1. The invention relates to turning bodies and consists particularly of using bearings, certain ones of which are magnetic, for bringing about their guiding and moreover opposing constant forces developed by these bodies, in particular their weight; it is characterized by the fact that at least the assembly of the components of which said turning bodies are composed is such that these components, when taken away from their position of balance, develop forces which are slightly variable with this displacement, at least relatively with respect to the restoring forces of the naturally stable magnetic bearings with which said bodies are combined; these bearings can be magnets or electromagnets without servo control, and are completed, for guiding according to the directions of space in which the balance of the turning body remains unstable, by hydro and aerodynamic, mechanical or electromagnetic bearings which are servo controlled.

2. Embodiments of the invention having the following particularities considered alone or in any possible combination:

a. A drive motor which, in case of misalignment of the rotor, develops a slight radial reaction, such as an electric motor with a flat rotor, is combined with a device for radial guiding

possible to prevent damage to wheel 5 in case of possible misalignment, on the same basis as bearing surface 24 (Figure 3).

Using these different figures, it is possible to see that in the case of progressive displacement of the moving body from its ideal position, the gaps must be chosen so as to involve successively:

In the radial direction, magnetic bearings 2, then stabilizer 6, and finally mechanical safety components 24 and 25;

In the axial direction, servo controlled electromagnetic stop 7, then mechanical safety stops 8a and 8b, and this within the limit of the possible variants of the gaps of compressor 5, on one hand, and of rotor 4, on the other hand, and finally other components in which play is arranged, such as the magnetic or electromagnetic bearings.

It furthermore goes without saying that it is easy for the technician to transpose the embodiments described above to a similar assembly with vertical axis, whose advantages can be considered to be lesser, since the mechanical friction risks being higher, but which is described, at least diagrammatically, by Figure 6 which should be compared to Figure 1.

In this diagram, the weight of the moving body is supported by stable magnetic stops 3a and 3b. They can be produced by means of toric ferrite cores, if necessary assisted by permeable reinforcements of suitable profile. A simple diagrammatic stable magnetic stop example is represented in Figure 7 and is made up of toric ferrite core 46 with the same axis as shaft 1 turning and connected to it, cooperating with stationary concentric toric ferrite core 47, of greater diameter, their cylindrical surfaces opposite one another being pole surfaces of opposite signs. Figure 6 represents other non-exclusive but improved executions.

With the weight exerted towards the bottom of the figure, and with the motor and receiver, if they are of the types already described above, introducing forces which are only slightly variable on both sides of the position of balance, it is possible to consider magnetic stops 3 to have the dual role of suspension and restoration to a position of balance. Although they cooperate in these two functions, by simplifying, it is possible to attribute more particularly the role of suspension to the upper stop and restoring to the lower stop. This stop 3a has a symmetrical construction, and even though the drawing shows pairs of toric ferrite cores 36-37a and 37b-38 functioning by repulsion (ferrite cores 37a and 37b being mobile), a symmetrical assembly with attraction can be substituted for them. Reinforcements 39 and 40 made of permeable material are used to reduce the magnetic losses. The pole surfaces opposite one another are flat and have the same sign [polarity]. In contrast, upper stop 3b has attracting upper pair 41-42 and repelling lower pair 42-43, assisted by reinforcements 44 and 45. In this case, the flat pole surfaces opposite one another respectively have opposite signs and the same sign. If the dimensions and magnetizations of all the ferrite cores have the same values, the lower and upper

of the turning body by stable magnetic bearings; the axial guiding is brought about by mechanical stops or stops of different nature other than stable magnetic;

b. In the arrangement according to a, the axial guiding is ensured either by at least one servo controlled electromagnetic stop, or by an aerodynamic stop in the case, for example, of a centrifugal compressor provided for this purpose with a turning balance plate situated opposite from the suction of the wheel and subjected in the appropriate direction to the discharge pressure;

c. A drive motor which, in case of axial displacement of the rotor, develops a slight axial reaction is combined with stable magnetic stops; the radial guiding is brought about by magnetic bearings or bearings of different nature other than stable magnetic;

d. Mechanical safety bearings made of a material with a low friction coefficient, which can however be rudimentary, possibly, by their arrangement with gaps smaller than those of the components which are to be protected, prevent damage which would be caused by extensive displacement of the turning body;

e. Added to the magnetic bearings and stops is any so-called stabilizing deadening device which acts according to their direction of stability;

f. The rotary machine driven by the motor is itself balanced radially and axially, and the possible forces of instability exerted during a displacement from the position of balance remain slight in view of the stabilizing forces of the magnetic bearings with which it is combined.

3. A device for guiding and support of a compressor with horizontal axis according to the invention, which has the following particularities considered alone or according to the various possible combinations:

a. The magnetic bearings are made up of cores made of ferrite with rectangular cross section, which are coaxial to the rotor and alternately stationary and mobile, and arranged with their poles opposite one another with opposite signs;

b. The mechanical stops are ball bearings;

c. At least one servo controlled electromagnetic has a reinforcement which can be magnetized, which is coaxial to the shaft and which can move with it, cooperating magnetically with a stationary coil whose field can vary under the action of the displacement, in the air gap of a stationary differential transformer, of a coaxial permeable sight connected to the shaft; some means of amplification being provided which make it possible to supply said coil with power from the signal provided by said transformer, the whole producing a servomechanism with closed loop by known electric means;

d. At least one stabilizer is involved in the reduction of a misalignment, which is produced by a contact made of a material with little friction, which is compelled to move radially by any known ordinary means of guiding, and which is brought back by an elastic component

toward the shaft from which it is separated by a reduced gap when this shaft is in its normal position of balance;

e. mechanical safety stops and bearings constructed with gaps are arranged around the shaft, constituted by means of simple surfaces made of material with a low friction coefficient, such as graphite-teflon, and are involved only for protecting the mobile components from contact with the stationary parts;

f. The turning assembly, with the exception of the wheel, is contained in a sealed casing which is maintained by a suitable pipeline at a pressure close to that predominating upstream from the compressor.

4. A device for guiding and support, according to the invention, of a turning body with vertical axis, which has the following particularities considered alone or according to the various possible combinations:

a. The magnetic stops are made up of ferrite cores with rectangular cross section, with grains oriented so as to have poles on their flat surfaces and arranged in series at each end of the shaft, concentric to this shaft;

b. The lower magnetic stop is made up of ferrite cores, the pairs of which framing the upper and lower air gaps create magnetic forces of the same nature;

c. The upper magnetic stop in contrast is made up of ferrite cores, the pair of which framing the upper air gaps are attracting, and those framing the lower air gaps are repelling;

d. At least one mechanical bearing, situated, if it is the only one, above the center of gravity of the turning body, is used for radial guiding of this body and can be made up of a journal of the shaft cooperating with a stationary bearing made of material with a low friction coefficient such as graphite-teflon;

e. A stabilizer, which acts at least axially, can be situated at one end of the shaft and be made up of a spring contact cooperating with a suitably shaped housing for it.

Fig. 1

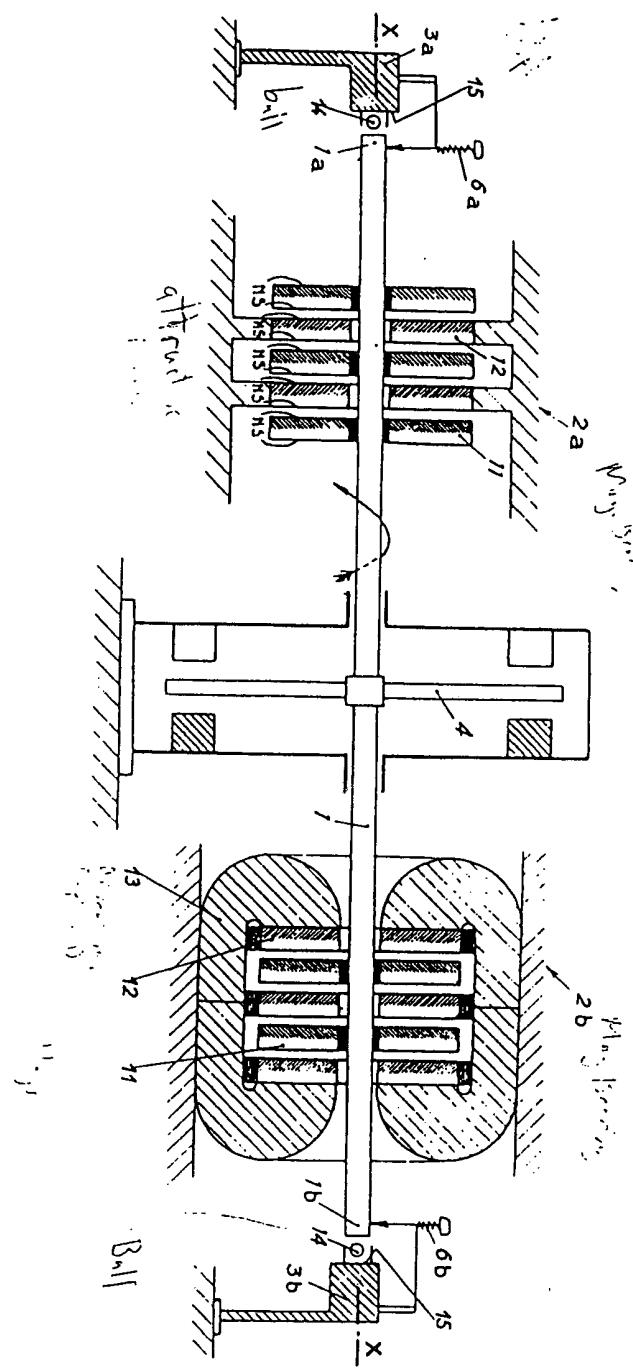


Fig. 2

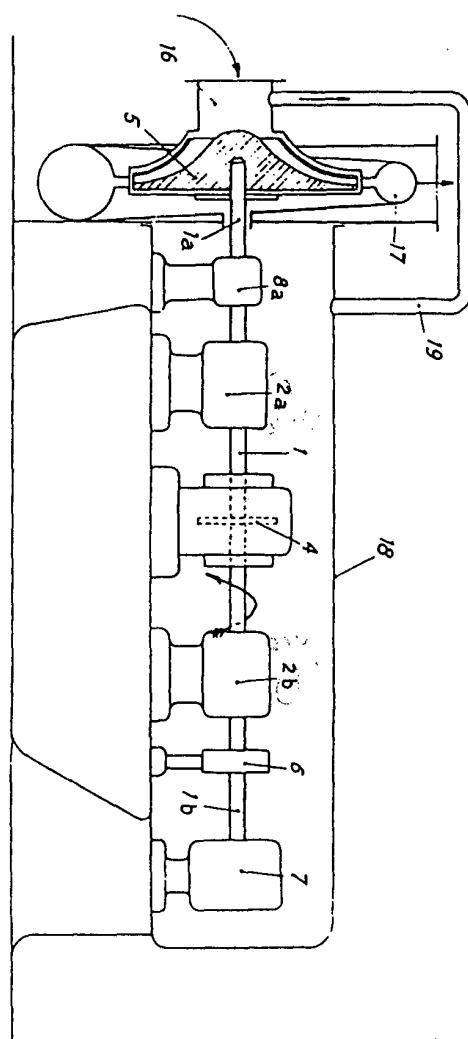


Fig. 3

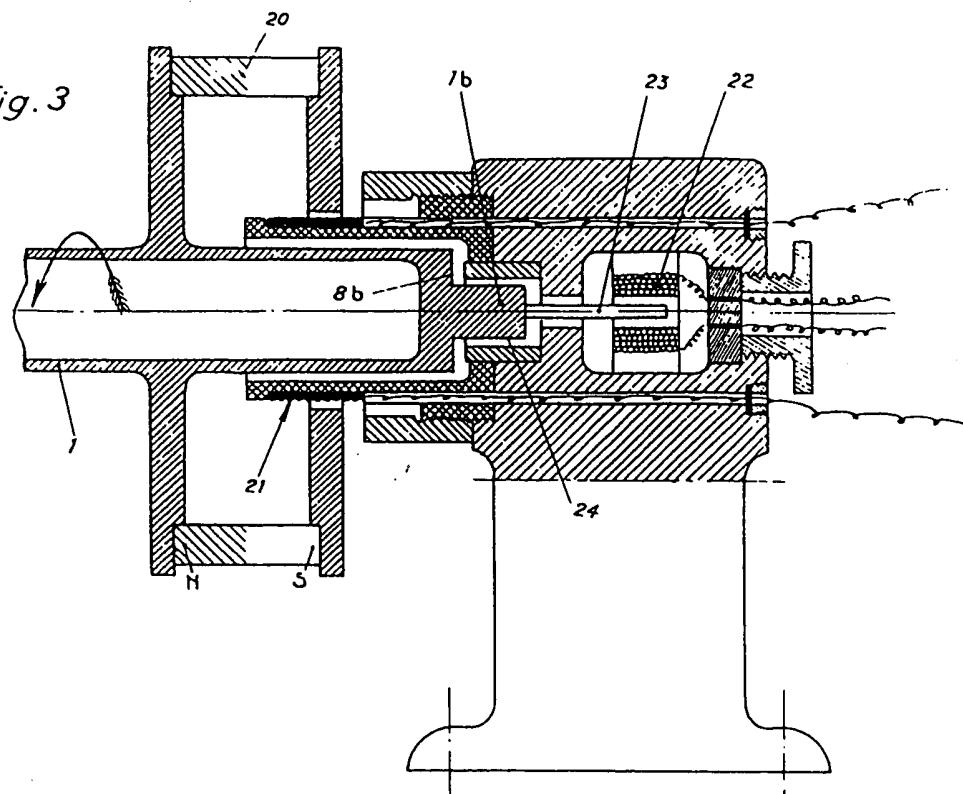


Fig. 4

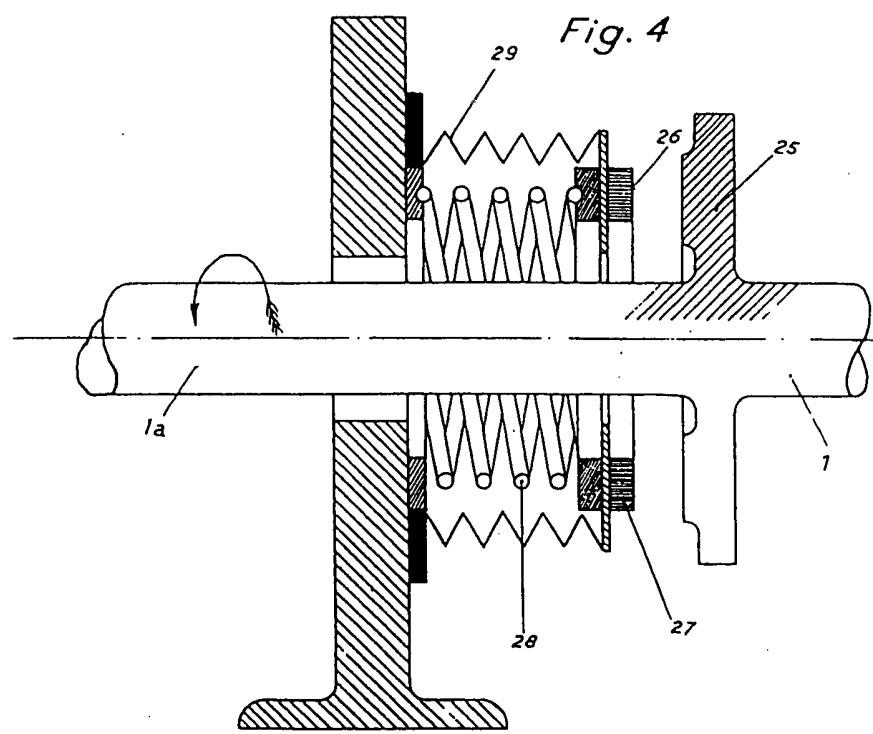


Fig. 5

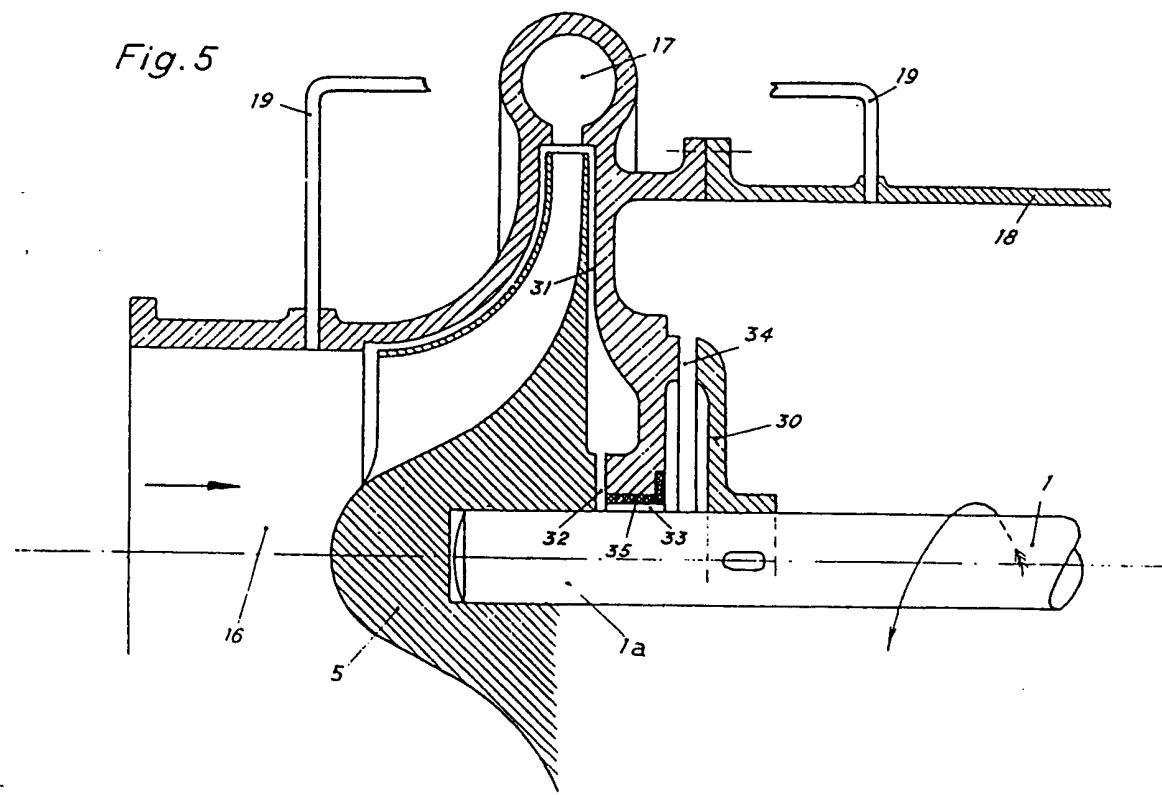
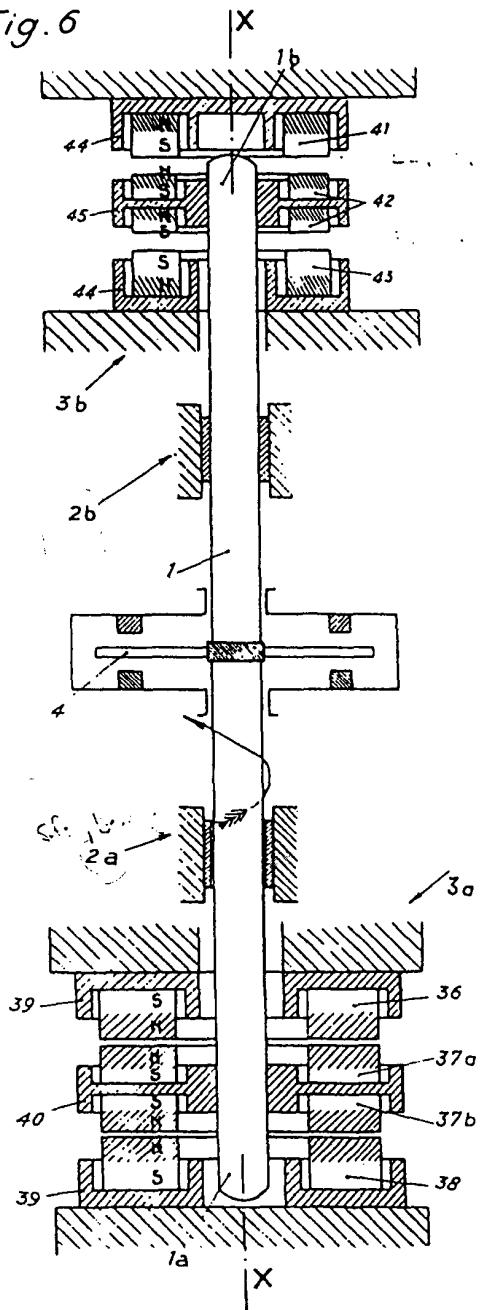


Fig. 6



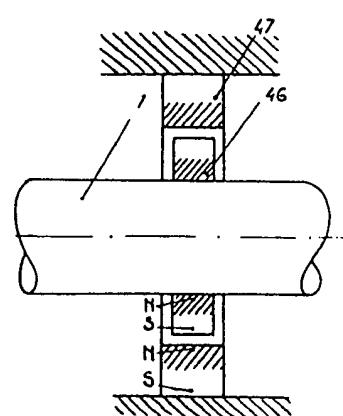


Fig. 7